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## Modulation of urban atmospheric electric field measurements with the wind direction in Lisbon (Portugal)

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**Abstract.** Atmospheric electric field measurements (potential gradient, PG) were retrieved in the urban environment of the city of Lisbon (Portugal). The measurements were performed with a Benndorf electrograph at the Portela Meteorological station in the suburbs of the city (NE from the centre). The period of 1980 to 1990 is considered here. According to wind direction, different content and types of ions and aerosols arrive at the measurement site causing significant variations to the PG. To the south there are significant pollution sources while to the north such sources are scarcer. The Iberian Peninsula is found east of the station and the Atlantic Ocean covers the western sector. Wind directions are divided in four sectors: *i*) NW:  $270^\circ \leq \theta \leq 360^\circ$ ; *ii*) NE:  $0^\circ \leq \theta \leq 90^\circ$ ; *iii*) SE:  $90^\circ \leq \theta \leq 180^\circ$ ; *iv*) SW:  $180^\circ \leq \theta \leq 270^\circ$ . Analysis of weekly cycle, caused by anthropogenic pollution related with urban activity, was undertaken for each wind sector. NW sector has been shown to be less affected by this cycle, which is attributed to the effect of marine air. The daily variation of NE sector for weekends reveals a similar behaviour to the Carnegie curve, which corresponds to a clean air daily variation of PG, following universal time, independent of measurement site.

### 1. Introduction

Surface atmospheric electric field (potential gradient, PG) measurements in urban environments are affected by anthropogenic action [1]. The main agents of these influences are pollutant aerosols from traffic, heating and industrial activity. According to the geographical location of pollutant sources around a measurement point, different winds bring different ion and aerosol contents; for that reason a significant modulation of PG is expected according to wind direction. Such modulation has been observed in different situations: high-voltage power-lines [2], traffic routes [3] and coastal regions [4].

The modulation caused by the wind direction can be of great importance as it varies the measurement conditions, for example, in an urban environment air with different pollutant content can reach the measurement site. The comprehension of such modulation can be achieved in long time series of PG, as in the case of Portela-Lisbon historical records [5]. This is because it enables the selection of a long time series measured with a characteristic pollution type, if the proper wind sectors are selected. Obviously, such possibilities are of huge value, for instance, in studies related to the Global Electric Circuit where pollution drastically perturbs any results and clean air is desirable.



For that reason, in the present work the historical PG time series of Portela-Lisbon is divided in four different wind sectors and the hypothesis of wind direction modulation is tested.

## 2. Data and methodology

PG was recorded with a Benndorf electrograph coupled to a radioactive probe installed at 1 m height at Portela meteorological station (suburbs of Lisbon, Portugal); more details can be found in [1,5]. Due to the nuclear fallout of the 1960's and 1970's, only the period from 1980 to 1990 is considered. Moreover, only non-negative values of PG are selected as negative ones often correspond to precipitation and cannot be considered. Otherwise, high positive PG values can occur as a consequence of pollution, as in case of fire. This phenomenon occurred during the historical Chiado's fire in Lisbon downtown [6]. Lisbon is situated on the north margin of the Tagus River and Portela station (close to Lisbon airport) is located to its northeast. Traffic and urban heating are the main causes of pollution in the city. In the 1980's the most significant pollution sources could be found in the south margin of the river (Setubal region). At the east of Lisbon the Tagus river basin and the Iberian Peninsula can be found, while the Atlantic Ocean is found to the west. Thus it is expected that winds from different directions should modulate PG as they are expected to contain different air contents. At Portela south winds bring pollution from the city mixed with the pollution from industry, west winds transport some pollution from the city mixed with marine aerosols, north winds carry less pollution mainly from the city activity and the east winds carry also continental aerosols.

To evaluate the effect of the anthropogenic pollution in each sector the procedure developed in [1] is used. It is based on the signature left by the weekly cycle of urban activity in air pollution and hence in PG. In [1] the PG was separated into workdays, Mondays to Fridays,  $PG_{workdays}$  (WD) and weekends, Saturdays and Sundays,  $PG_{weekends}$  (WK). It is expected that PG has higher values for workdays if compared with PG for the weekends, because workdays have more pollution. Thus, to evaluate the difference between workdays and weekends, the relative difference is used:

$$\Delta PG (\%) = (PG_{workdays}/PG_{weekends} - 1) \times 100. \quad (1)$$

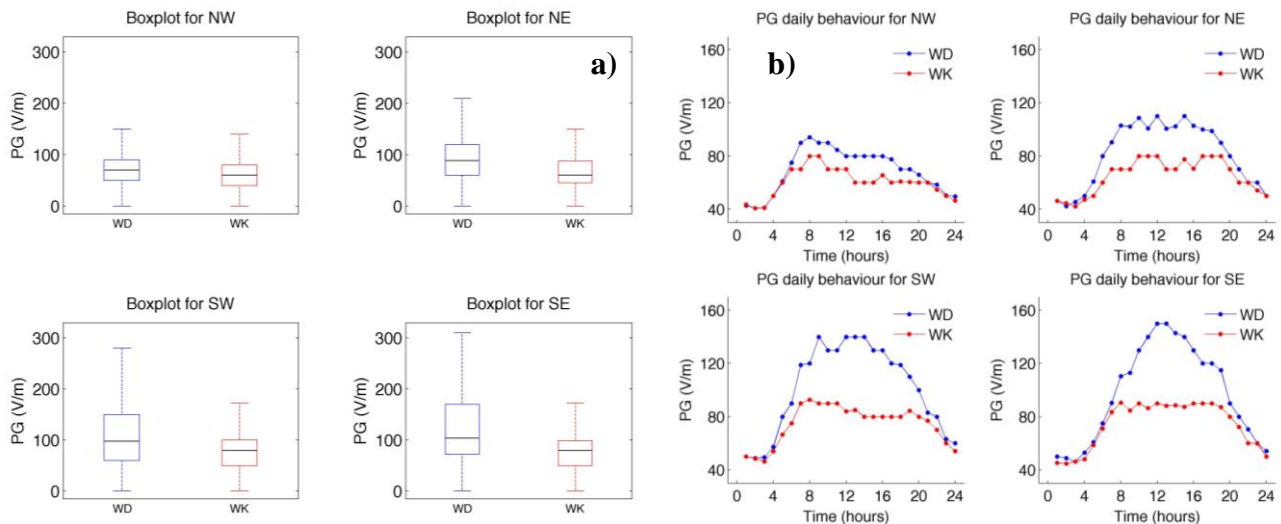
The comparison of the daily cycle for workdays and weekends is also very informative and such method is used here. Finally, the Lomb-Scargle Spectrum (LSS) technique is used to identify the presence and importance of the weekly cycle in each wind sector. This technique was used in [1] and described in detail there. The program used is an LSS implementation developed for MATLAB® [7].

## 3. Results and discussion

### 3.1. Boxplot analysis

Figure 1a shows the boxplots of PG values for each wind direction separated by workdays (WD) and weekends (WK), for clarity outliers are not represented. It is evident that: 1) NW sector shows little variation between workdays and weekends having a small relative difference of the medians for workdays, 70 V/m, and for weekends, 60 V/m,  $\Delta PG \sim 17\%$ , consistent with low levels of anthropogenic pollution; 2) NE sector presents more variability in the workdays if compared to the weekends. The median for workdays is 87 V/m and for weekends is 60 V/m, corresponding to  $\Delta PG \sim 45\%$ , which is a high value and is mainly due to the low median value for the weekends; 3) SE sector shows the higher variability of PG for workdays of all sectors, again the median for the weekends, 80 V/m, is lower than that of the workdays, 104 V/m, having  $\Delta PG \sim 30\%$ . This behavior shows evidence of a significant influence of anthropogenic pollution; 4) SW sector has a median PG value for the workdays of 98 V/m, and for the weekends, 80 V/m, i.e.,  $\Delta PG \sim 23\%$ . These results show that all the sectors are affected by the weekly cycle; nevertheless, the NW tends to be the least affected. This feature can be interpreted as a consequence of lower pollution levels and the presence of marine air

due to the western winds from the Atlantic Ocean. In fact, marine air is known to increase atmospheric conductivity [4] with the consequently reduction PG.



**Figure 1** a) Boxplots of the PG for the different wind sectors divided in workdays (WD) and weekends (WK); b) Daily behaviour of the median PG values for 1980 to 1990 separated in workdays (WD) and weekends (WK).

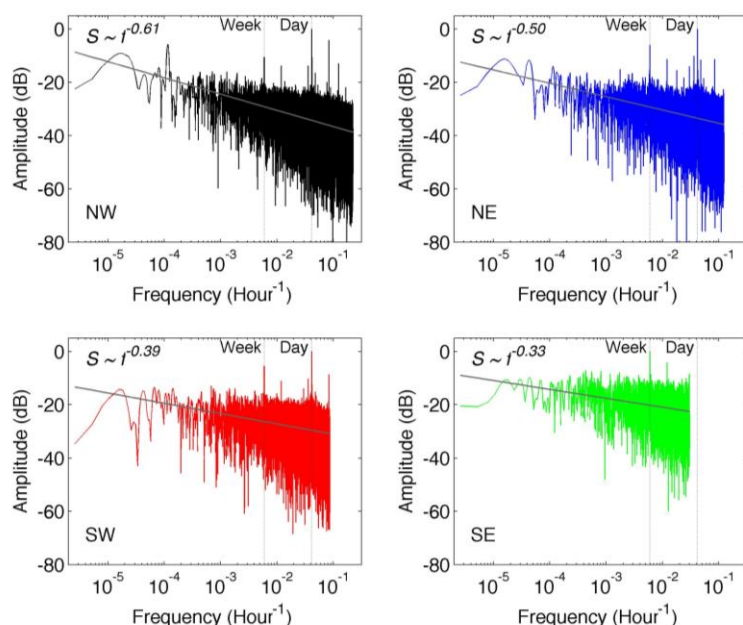
### 3.2. Daily behaviour

Figure 1b presents the daily behaviour of the median PG values for the studied period and considering workdays and weekends in separate. On the one hand the northern sectors, NW and NE, show little difference between the daily behaviour of the workdays and the weekends. Actually, the NW sector shows the lowest values of the sectors. On the other hand the southern sectors show the most significant difference from the workdays to weekends, in particular, the SE and SW sectors show a prominent disparity in the period 8.00 a.m. – 8.00 p.m., the period of greatest anthropogenic activity. This aspect may be interpreted as the signature of pollution coming from industries south of Tagus River, which are most active in that period. Lastly, the daily variation of NE sector for weekends reveals a similar behavior to the Carnegie curve, the background 24 cycle of atmospheric electric field caused by variations in global thunderstorm activity [8].

### 3.3. Lomb-Scargle Spectra

The LSS for each of the four wind sectors are depicted in figure 2, where a clear modulation with wind direction can be observed. The NW and NE have higher slopes with  $n$ -exponents around, 0.61 and 0.50, correspondingly. The SW and SE have lower  $n$ -exponent values, 0.39 and 0.33, respectively. These lower values are compatible with measurements taken under more polluted air as pollution tends to induce spectral dispersion which flattens the spectra [1,9]. Moreover, the presence of the weekly cycle is observed in all wind sectors, less pronounced in the case of NW sector. This observation is compatible with low  $\Delta PG$  found for this sector and could be another indication of the effect of marine air as it tends to increase the conductivity, in contrast to the effect of pollution which has the opposite effect. The NE sector shows a marked weekly cycle even though the pollution levels should be lower as compared with the sectors from the south. This can be an indication that pollution from the city, mainly traffic, should be the key pollution source in this sector. Otherwise, pollution from the south is a result of industrial activity and, in principle, less affected by the weekly cycle as

many industries continue in activity at the weekends. Finally, all sectors, except the SE, clearly show, besides the daily cycle, a half-day cycle.



**Figure 2.** Lomb-Scargle Spectra corresponding to the four wind sectors. The following parameters were used  $hifac=1$  (that defines the frequency limit as  $hifac$  times the average Nyquist frequency),  $ofac=4$  (oversampling factor). This exponent, ( $n$ -exponent) is defined from the asymptotic spectral amplitude,  $S$ , with the frequency,  $f$ , usually written as  $S \sim f^{-n}$ .

#### 4. Conclusion

A clear modulation of atmospheric electric field measurements with wind sector/direction is observed in the mean daily cycles. NW was found to be the sector less influenced, which has been attributed to the effect of more conductive marine air. The daily variation of NE sector for weekends reveals a similar behavior to the Carnegie curve. Finally, the effect of pollution of industries located to the south of Lisbon on PG is found to be strong in the period 8.00 a.m. – 8.p.m.

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